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**Perspective**

# The human and social impacts of climate overshoot

Andrew Kruczkiewicz[a,b,c,*], Zinta Zommers[d,e], Joyce Kimutai[f,g], Matthias Garschagen[h] and Joshua Fisher[a,i]

[a]Climate School, Columbia University, 2910 Broadway, New York, NY 10025, USA
[b]Red Cross Red Crescent Climate Centre, Anna van Saksenlaan 50, 2593 HT The Hague, the Netherlands
[c]International Institute for Geo-Information Science and Earth Observation, University of Twente, Hallenweg 8, 7522 NH Enschede, the Netherlands
[d]United Nations Office for the Coordination of Humanitarian Affairs, UN Headquarters, New York, NY 10017, USA
[e]Perry World House, University of Pennsylvania, 3803 Locust Walk, Philadelphia, PA 19104, USA
[f]Kenya Meteorological Department, Dagoretti Corner, Ngong Rd, P.O. Box 30259, 00100 Nairobi, Kenya
[g]Centre for Environmental Policy, Imperial College London, 16-18 Prince's Gardens, London SW7 2BT, United Kingdom
[h]Department of Geography, Ludwig-Maximilians-Universität München, Luisenstraße 37, 80333 Munich, Germany
[i]Network for Education and Research on Peace and Sustainability, A601, Advanced Science of Matter, Hiroshima University, 1-3-1 Kagamiyama, Higashi-Hiroshima 739-8530, Japan
*To whom correspondence should be addressed: 2910 Broadway, New York, NY 11025, USA. Email: ajk2207@columbia.edu
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## Abstract

The scientific community has produced increasingly robust knowledge and evidence of the physical impacts of warming on time scales of tens of decades and longer. However, the social and humanitarian impacts of climate overshoot remain largely unknown. As we quickly approach the Paris Agreement's aspirational target of 1.5 °C of global mean temperature rise, new and dynamic climate and social realities of climate overshoot must be considered and managed. Here, we outline 5 factors influencing human and social climate overshoot impacts, describe potential post-peak behavior that would lead to varied impacts, and call for enhancing action to fill pressing knowledge, data, and policy gaps to understand the risks to human and social systems.

**Keywords:** climate risk management, temperature overshoot, disaster risk management, climate variability, environmental policy

In the early 2000s, the possibility of overshooting certain thresholds in global mean temperature (GMT) gained more attention in academic spaces (1, 2). Generated data and related discussions promoted awareness of the potential for cascading and potentially irreversible impacts to planetary systems (3). Over subsequent years, the scientific community has developed increasingly robust knowledge and evidence of the physical risks of such warming on time scales of tens of decades and longer. However, there has been little systematic knowledge and evidence production related to the social and human impacts of climate overshoot, particularly for the communities who will be most directly, severely and most urgently impacted, and on the time scales that matter most, in terms of informing when, where and to what extent risk mitigating actions should be prioritized (and deprioritized) (4, 5).

The latest Intergovernmental Panel on Climate Change assessment has shown that, under current Nationally Determined Contributions (NDC)s, we are on track to significantly exceed 1.5 °C GMT before the 2050s (6, 7). Full implementation of both unconditional and conditional NDCs could lead to up to 2.6 °C warming of GMT. Updated NDCs expected in 2025 must deliver unprecedented cuts to emissions by 2030, as well as include specific and transparent sectoral benchmarks and means of implementation (8). However, only a minority of countries have submitted updated NDCs, significantly increasing the likelihood of a period of time, likely decades or longer, with significant climate overshoot, i.e. a phase in which warming exceeds the 1.5 °C mark before drawing down below it (Fig. 1) (9). Now is the time to consider not only critical questions leading the world to face choices, such as those related to rate of recovery and stabilization, but also the ways in which various risk reduction approaches are implemented at the right time, and at a sufficient scale.

Doing so is critical as the appropriateness of approaches, such as various types of anticipatory humanitarian action, will fluctuate over time within different overshoot scenarios, at various times before, during, and after primary, and subsequent relative, peak temperature periods (10–12).

With the improvement in global climate models, downscaling approaches and integration of artificial intelligence and machine learning–centric and machine learning–derived products and processes, the scientific community has been able to illuminate many of the physical risks the world is likely to experience after crossing 1.5 °C GMT (2, 3, 7). However, the human and social consequences of temperature stabilization or decline post–1.5 °C GMT for areas such as food security, health, displacement and mobility, and humanitarian action have received far less scientific attention (5, 13, 14), even as demand increases for the development of relevant policy (15). The lack of evidence-backed insight leads to significant challenges in decision making related to disaster management

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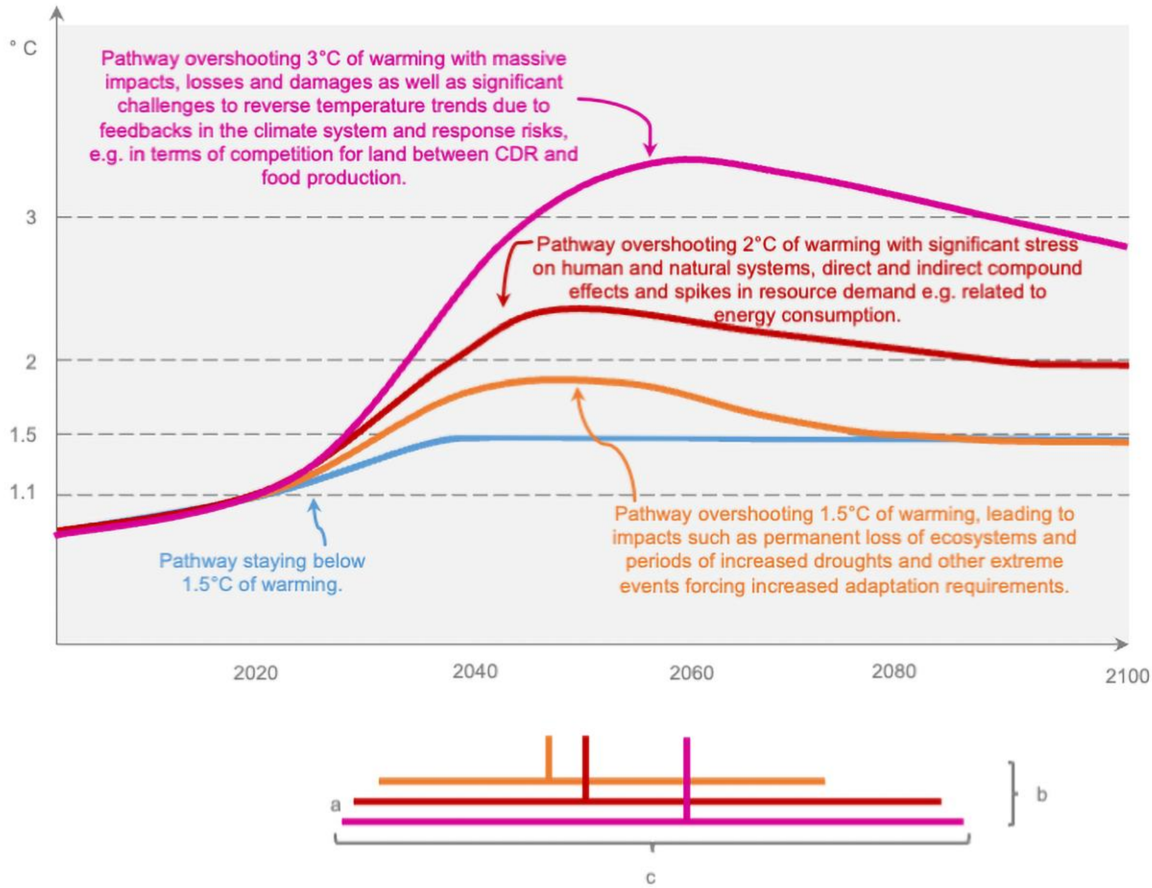


**Fig. 1.** A schematic representation of climate change impacts of relevance for the humanitarian sector, including (a) the timing of temperature exceedance, (b) the peak warming, and (c) the duration of overshoot.

and humanitarian action—the exact spaces that are responsible to support vulnerable populations dealing with climate impacts—and those that must anticipate and be responsive to changes in the standard operating procedures of today (16, 17). The paucity of datasets sets the stage for the risk of compounding already complex processes with mis- and underestimation of impacts (18).

At the 80th anniversary (2025) of the United Nations, debates and reflections on the roles, responsibilities, and ultimately the future of the humanitarian sector, increasingly referred to as the Humanitarian Reset, are taking place. Overshoot scenarios, and differences in the associated direct and indirect impacts of each scenario, must be central to these discussions. As an applied climate research community, we are at a critical juncture in which there is still time to build the evidence base for likely overshoot scenarios, and act on such evidence, but that window is rapidly closing. Further, the amount of time available within such a window is becoming increasingly uncertain due to changes in geopolitical contexts specific to both climate change adaptation and mitigation, and more broadly related to secondary and indirect impacts related to shifts in trade, partnerships, and international aid and development priorities (19, 20). In describing both direct and indirect social impacts, there is a need to further enhance, and potentially reframe, research on the ecological impacts and feedback to physical systems (21, 22). And in doing so, this more comprehensive approach must include modelling a diverse range of interactions between direct and indirect impacts across various sectors, such as water, food, energy, and the humanitarian sector (23).

To help anticipate and prepare impacts for climate overshoot impacts, and in moving beyond mitigation-focused solutions, we propose that policymakers and planners begin to consider 5 areas: 1) peak warming and the duration of overshoot and the timing of arrival, 2) the geographic distribution of overshoot effects, 3) the level of future exposure and vulnerability in the affected ecosystems and societies, 4) adaptation limits, and 5) the responses to reverse overshoot, e.g. through carbon dioxide removal (CDR), and dynamics of reversal. There are growing efforts to explore these factors for specific sectors, applications, and communities (24, 25). However, it is critical that future programs and activities, such as those related to solar geoengineering, focus on the consequences for the most vulnerable populations, and where possible, the opportunities for the most vulnerable populations to build resilience and thrive, acknowledging the reality of reprioritizing various actions as impacts vary over time, over different phases of recovery (26).

## Peak warming and duration of overshoot

Multiple IPCC risk assessments, and observations, have clearly shown the sensitivity of ecosystems and societies and how they are impacted by increased warming. In fact, the latest IPCC report has shown that ecosystems and social systems are even more sensitive to warming than previously assessed, meaning that risks are higher at 1.5 °C or 2 °C of GMT warming than previously assumed (27). Reversing these impacts is not feasible for many systems (e.g. sea level rise), even if temperatures are, after a period of overshoot, brought back down to below these thresholds. This could result in long-term changes in what humanitarian needs look like and a lack of predictability in how those needs will evolve over time both in terms of the physical hazard (e.g. persistence of sea level rise post–peak GMT) and socioeconomic (e.g. indirect and compound effects on social systems) repercussions of climate overshoot.

In addition, as scale and magnitude of impacts depend on the duration of overshoot, certain systems may be able to buffer shorter periods of overshoot, such as aerosol pollutants, compared with groundwater, for example (27). However, even for such systems that have a certain degree of resilience, the stress testing needed to understand the impacts on the most vulnerable populations within the contexts of high-vulnerability populations at sufficient levels of granularity has not been sufficiently conducted—nor have the shortcomings of a lack of appropriate disaggregation been robustly described or communicated effectively. Irreversible impacts may only emerge after a duration threshold is achieved, but earlier impacts may emerge continuously in various forms. Further, even for systems in which impacts could be reduced or reversed in principle after, additional direct and indirect impacts are to be expected during the overshoot, including pre- and post-peak (recovery) periods, many of which are then irreversible in turn. A limited number of decades with increased droughts or wildfires, for instance, will lead to additional economic and human losses, at the individual and community levels, which are not reversible, even if the intensity of droughts and wildfires themselves might be. The longer the duration of climate overshoot is, and the more volatile it is in terms of changes in temperature trends and direction, the greater the drain on financial reserves and the ability to prioritize and allocate resources to anticipate and absorb shocks.

## Geographical amplification

Despite the fact that the international policy discourse is concerned with globally averaged levels of warming, the additional impacts from temperature overshoot will not be distributed equally across the globe in space, time, and magnitude. First, regional amplification of warming and climate feedbacks can be expected to lead to situations in which the same level of global overshoot (e.g. exceeding 1.5 °C for 3 decades up to a peak warming of 1.8 °C) will affect some regions more significantly than others (28). The Arctic and West and Southern Africa, for example, are warming faster than the global average (24). Second, areas experiencing each increasing exposure and vulnerability, along with increasing hazards stemming from overshoot are nonuniformly distributed globally (29). While the dynamics of exposure and vulnerability in overshoot bears similarity to disaster risk in a preovershoot world, and even in a world before substantive climate change, a post–1.5 °C world may include nonlinearities of exposure and vulnerability from global change, interacting with both known and unknown nonlinear impacts induced by overshoot.

Both aspects—regional climate amplification and high social vulnerability—are co-occurring in many parts of the world. For example, in addition to hosting some of the most vulnerable ecosystems and communities, the Arctic (or polar) areas experience amplification driven by a variety of factors including snow and ice decline, which has led to changes in land cover and land use, in addition to increasing temperatures, each driving shifts in livelihoods (30). Likewise, regions with hydrological amplification in Africa are also those with some of the highest levels of social vulnerability globally (27). To support the principles of an equitable and just transition, the interaction between overshoot impact and the well-being of the most vulnerable communities must be better understood.

## Timing of arrival

The latest IPCC assessment report clearly showed that the speed of potential adaptation of climate change affected systems is a major determinant of risk outcomes. As systems need time to adapt, such as through species mobility and migration in ecosystems or infrastructure development in human systems, the risk of loss and damage may be higher the faster temperatures are increasing and the sooner extreme climate and weather events manifest. Even what is defined as a sufficiently resilient system today may weaken, or fail to evolve as quickly as needed during overshoot—for example, in reaction to inflection and the changes in concavity during recovery. For coastal cities, for instance, the retrofitting of existing infrastructure for storm surge protection can take several decades (15), and such actions, if effective, will only address one type of flood risk, with river flood risk and flash flood risk changing at different rates and becoming a new occurrence in certain areas, demanding more attention to reprioritization of policy and allocation of resources (25, 31).

## Adaptation limits and trends in vulnerability

Limits to adaptation will increasingly be exceeded with significant losses and damages becoming prevalent (32). The compounding and cascading nature of risks and impacts only serves to worsen and complicate vulnerability (8). This is due to the dynamic and evolving nature of climate change impacts, with cascading effects across various sectors, ecosystems, and communities. Many of the unanticipated impacts and poorly characterized risks will lead to maladaptation, leaving the most vulnerable communities (once again) disproportionately ill-prepared, during a time of increasingly complex weather and climate extreme events (33): for example, the overreliance of land to sink carbon, and the lack of understanding of direct and indirect impacts on land cover and land use and how these will feed back into overshoot-modified systems, such as food, health, and energy systems. Efficacy of natural sinks is expected to reduce significantly as $CO_2$ levels in the atmosphere continue to increase, as overreliance will present enhanced and new types of competing interests.

### Overshoot reversal dynamics

Post-peak behavior is significant, and currently underestimated in importance, when considering human and social impacts. Reversal of GMT will require negative emissions and increased CDR deployment. Land- and ocean-based methods for CDR with comparatively low risks, e.g. afforestation and wetting, will create substantial additional demand for land and put pressure on existing systems, potentially leading to conflicts with food production and other uses. While there has been a wide acknowledgment of the uncertainties related to CDR, the overly simplistic framing, along with the untested nature of the technologies and the potential to disrupt and jeopardize fragile climate agreements, demand more deliberate and substantive attempts to integrate risks and benefits to the humanitarian sector not only of the development and deployment of the technology, but also related to governance and decision making.

Recovery from overshoot is likely to consist of various timescales with decreases and increases in GMT, as well as stagnant or stable (from a GMT perspective) periods, due to a variety of physical and social factors. Even stagnant or stable periods of GMT recovery, which may lead to periods of stability in impacts across certain sectors (such as those that can more quickly anticipate and deploy resources to pivot), can still drive unexpected shifts in risk for the most socially vulnerable populations and thus increasing demand

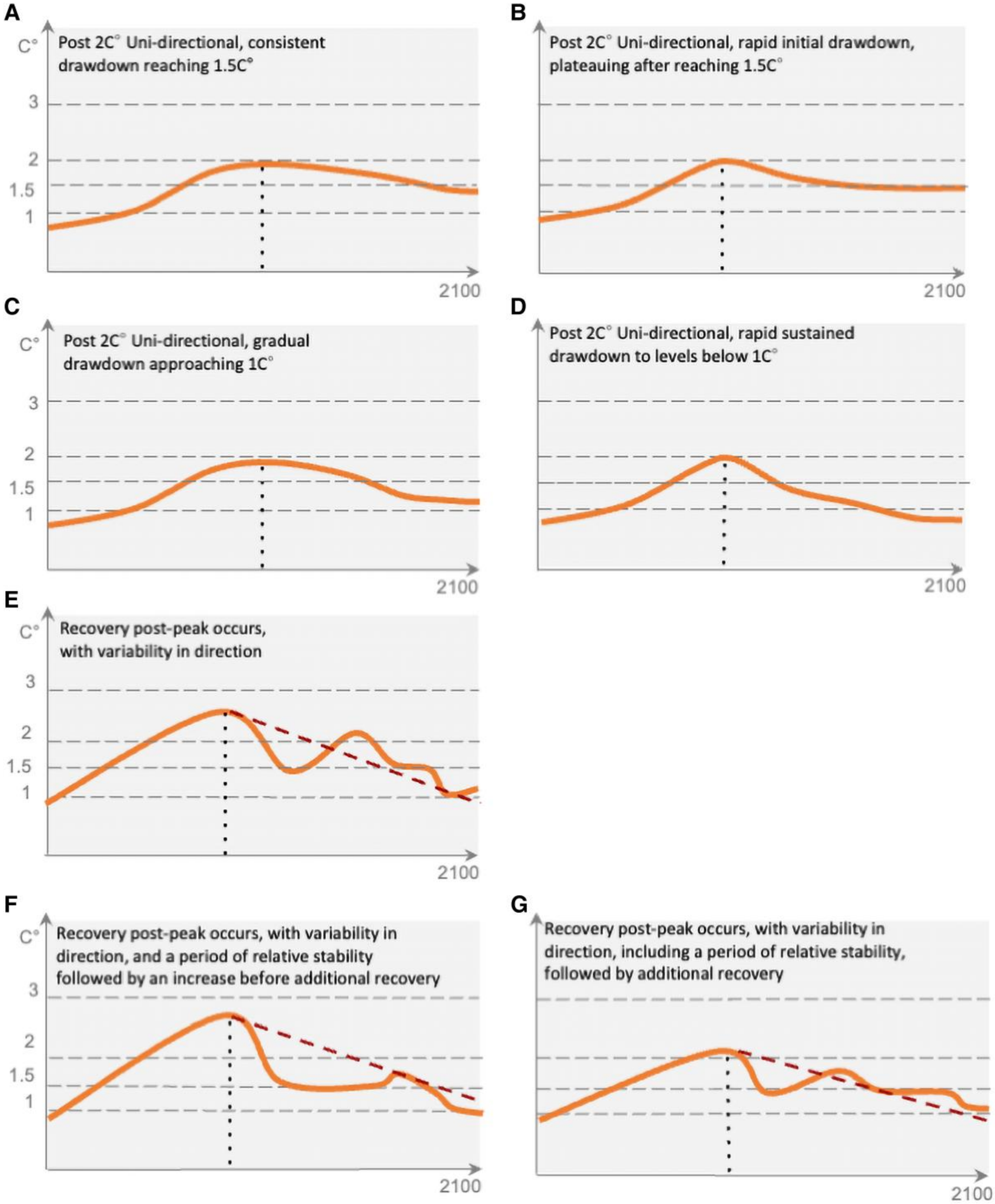


**Fig. 2.** Representations of various post-peak behaviors and the potential variability within recovery. (A–D) Unidirectional drawdown from the same peak (2C), at varying rates and extents. Despite the sustained drawdown, the variations in each scenario would carry different impacts and operational requirements for the humanitarian sector and disaster risk management. (E–G) Various representations of post-peak variability in duration, magnitude, and direction, where overall interpretation of behavior over a multidecadal period may be said to be "recovery" (red line). (E–G) Years and certain decades could still see increases in GMT. The oscillations between drawdown and rewarming, albeit at different rates and periods, would likewise carry unique planning and operational impacts in humanitarian operations, disaster risk management, and infrastructure development.

for resources in the humanitarian sector: for example, if overshoot-driven physical impacts on modes of interannual climate variability led to lagged impacts on seasonal precipitation patterns and trends in extreme events. These dynamics must be more clearly described, with their plausibility investigated, as evidence against their occurrence does not sufficiently exist, thus again leaving the most vulnerable to bear the weight of a foreboding risk of which the magnitude, intensity, and scope are unknown.

The shape and variability of the temperature curve used to model climate overshoot must be sufficiently relative to the intention for using it to inform discussions, actions, and ultimately policy development. Thus far, there has not been a robust representation of climate overshoot within either the academic literature or climate policy context that includes specific attention to variability of temperature post-peak that includes the potential for periods of relative stability during recovery, and subsequent trends, with assessments of temporal lags, for direct and indirect, and disproportionate, impacts.

Differences in how recovery may occur have been described; however, these representations, while potentially useful for certain applications, may be inappropriate or misleading for other use cases as they may underestimate both the uncertainty around and magnitude of impacts if a non-linear and variable recovery period occurs (Fig. 2E–G): for example, the ways in which energy pricing agreements are established may allow that sector to be more resilient to shorter interannual (compared with decadal) perturbations in recovery trajectory, whereas the humanitarian sector would be less equipped to attenuate a shift in impacts that may arise from a 5-year period of temperature increase within a larger 30-year period of recovery (Fig. 2).

## Managing societal impacts

The stakes for advancing knowledge and action on the impacts of overshoot are extremely high, as the short-term policy actions we take to respond to individual crises will influence mid- and long-term policy contexts, and particularly now as governments review and revise priorities related to strategies, partnerships, and motivations for international aid and humanitarian action (34, 35). If the humanitarian sector is not supported to promote an evolution to be stronger, more resilient, and flexible, there will be systemic barriers present in addressing new stressors in logistics and operations, leading to a persistence of known vulnerability and exposure, as well as to the production of new types of known and unknown risks (36, 37). As the future of the humanitarian sector is increasingly uncertain due to drastic funding reprioritization in recent years, strategic planning and policy design on the future of humanitarian action must include an overshoot lens. To do so, we propose the following guidance for a selection of the relevant groups involved in managing societal impacts:

For scientists, research on potential human and social impacts must be ramped up, increasingly prioritized, and broadened in scope to account for various post-peak behaviors, perhaps in the form of a coordinated global collaborative effort potentially similar to Model Intercomparison Projects (MIPs). Humanitarian sector interests must be more substantively and more visibly centered, in relation to overshoot, across each research, policy development, and translation into action, to ensure proportional and timely benefit for the communities set to experience the greatest burdens, and face the most direct threats, to their lives and livelihoods.

For humanitarian organizations, it is necessary, and there is a responsibility, to start or rapidly enhance strategic planning that accounts for a future in which there will be various evolutions of how impacts are experienced. Such planning should include developing scenarios for impacts that are both irreversible if occurring now and those that may be currently manageable yet may be irreversible if they happen during overshoot. Disasters of the future will lead to both new stressors and shocks, driving new and interrelated challenges in humanitarian funding, logistics, and operations that are at scales and complexity levels that may be impractical or impossible to address. Narratives within and around the humanitarian sector must evolve to embrace the reality of uncertainty, while better managing the tension between pragmatism and hope regarding the real and rising risks to the current approaches to humanitarian aid, disaster response, and international, sustainable development.

For governments, there is a growing need to strengthen NDCs to ensure that we have a realistic path to revert back to 1.5 °C GMT in ways that do not cause additional humanitarian needs and unforeseen impacts, and ensure that we avoid as many irreversible impacts as possible. Clearly acknowledging what we do not know must be incentivized, as these topics can support prioritization within interdisciplinary scientific research, to enable more appropriate and translatable science for policy. The immediate policy actions that we take to tackle individual crises will shape the longer-term landscape for policy and humanitarian response. These must occur now, with some of the initial steps including a review of policy and standards related to data collection to identify if and to what extent, and at which levels of resolution, people are representative at appropriate and relevant levels of granularity (38). Without robust global multilateral collaboration, across various types of government regimes, aligning climate solutions with a resilient and adaptable humanitarian sector, the future will bring about unprecedented challenges—ranging from resource shortages to logistical and operational complexities that could overwhelm existing systems, leading to transboundary impacts that are "unintended," yet potentially avoidable if the risk of such impacts are acknowledged and addressed now (39).

In conclusion, increasing our understanding of how social and economic systems will be impacted in climate overshoot is necessary to sufficiently identify, tailor, and implement the appropriate adaptation, risk reduction, and anticipatory action strategies in the years, and decades, ahead. In doing so, it is important to explore to what extent various sectors, such as the humanitarian, financial, and health sectors, as currently structured, funded, and operationalized can be resilient now and during the various phases of climate overshoot. Assessments of impacts that are likely to occur at specific thresholds, as well as across a range of timescales (such as decadal) must be conducted without a focus that is too strongly weighted toward tipping points and at peak temperature levels, as doing so will smooth out the inflections and variability that is high consequence to certain sectors specifically those that are influencing decision making, regulations, and policy related to balancing long term mitigation activities with the necessary attention on decreasing impact now.

The probability of unknown impacts, or at the least the probability for impacts that currently occur infrequently within geographic areas of interest, should also be made clear to allow for social and economic systems the best chance for preparedness and anticipation. These systems and associated governance structures must also be developed dynamically to be sufficiently structured to allow for accountability and monitoring and yet be sufficiently malleable to be reactive to changing conditions before, during, and after each peak temperature, perturbations across time scales, and periods of relative stability. A commitment to support the most vulnerable populations to address risks of the most extreme events is only the first step in adequately anticipating the impacts of overshoot on societies. We also need to commit to allocating resources for developing the knowledge and evidence needed to effectively prepare for and respond to the social impacts of overshoot. Ultimately, we must continue to pursue efforts to meet the Paris Agreement goals and avoid many of the worst impacts and complexities that may arise in climate overshoot; however, this pursuit must not lead to a de prioritization of planning for both a post–2 °C GMT world more broadly, as well as for distinct phases within climate overshoot.

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## Author Contributions

A.K., Z.Z., and J.F. led the drafting of this manuscript. A.K. and J.F. co-supervised the grants that partially funded the work underpinning this manuscript. J.K. led the literature review and synthesis of the analytical review underpinning the research. M.G. contributed to theoretical framing and development and production of graphics for this work. Z.Z. oversaw the United Nations Office for the Coordination of Humanitarian Affairs task order for this work and led theoretical framing and study design in partnership with A.K. and J.F.

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## Data Availability

The data underlying this article are available in the article and in its online supplementary material.

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